Laser-Ultrasonics Wave Generation and Propagation FE Model in Metallic Materials

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Abstract

Introduction: The Laser Ultrasonics technique based on a pulsed laser generating ultrasonic waves on materials is a valid Non-Destructive Testing (NDT) method for quality control and damage detection. It has been successfully applied for diagnostics purpose to composite materials in the aeronautical field. Complete models of the generation of the ultrasonic waves induced by the thermo-elastic stress produced by the impinging laser and their propagation would be of great interest for supporting the testing in the design of experiments phase. In this paper a FE model of the ultrasonic wave generation and its propagation in metallic materials has been investigated, being the ultimate goal of the activity the application of the Laser Ultrasonics to quality control of train axles.
Use of COMSOL Multiphysics®: The model has been created in COMSOL because different physics have to be considered in Laser Ultrasonics: thermo-elasticity for the ultrasonic wave generation due to the thermo-stress induced by the laser impulse and acoustics for the ultrasonic wave propagation within the material.
The complete characterization of the physical mechanism governing the emission and the interaction of the ultrasonic wave with the testing material allowed to perform a sensitivity analysis to the laser characteristic parameters (i.e. laser energy, diameter and pulse duration). Once validated the model, these parameters can be set in advance in relation to the measurement conditions, testing object material, damage typologies (i.e. surface or in-depth defect, convex defect due to fatigue or concave defect due to fretting, defect dimension).
The model have been calibrated and validated through an experimental test performed on aluminum and steel samples realized on purpose. The ultrasonic waves have been generated by a pulsed Nd-Yag laser emitting in the IR range and the surface displacement produced by the wave propagation measured by a Laser Doppler Vibrometer with a frequency bandwidth of 20 MHz, it allowing a high spatial resolution (less than 1 mm).
Results: The test sample realized in the model is shown in Figure 1 where the different bulk waves propagation is visible.
The comparison with the experimental results has been done along a scanning line (red dots in Figure 1) for different laser parameters. Figure 2 shows the numerical and experimental C-scans, i.e. the waterfall plot of the surface displacement in z-direction with respect to time (in abscissa) and spatial position (in ordinate), in the following conditions:
- laser diameter of 0.15 mm,
- laser energy of 140 mJ and,

and laser pulse duration of 12 ns .
Conclusion: The model results showed a good correspondence with the experimental ones, both in terms of propagation mechanisms (P, T bulk waves) and ultrasonic wave amplitude.
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Figures used in the abstract

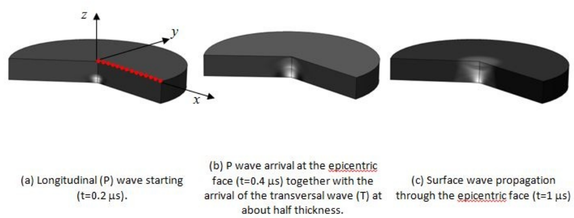

Figure 1: 3D visualization of the elastic waves propagation

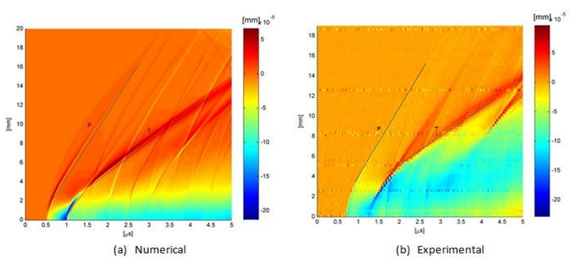

Figure 2: Waterfall of the u2 [mm] displacement in the z-direction through the epicentric surface, the position at 0 mm corresponds to the epicentric point